

Strangeness kinetics and energy dependence of hadron productions

Kinetic equation and conservation laws

Chemical equilibration from SIS to RHIC

Strangeness production energy dependence

Maximum relative strangeness content in heavy ion collisions

Work with:

P. Braun-Munzinger

J. Cleymans

D. Magestro

H. Oeschler

J. Stachel

Statistical-Thermal Models

- At freeze-out: the available particle phase space is occupied according to statistical laws
-> thermal distribution
- Chemical freeze-out: particle abundances are frozen in
- Thermal freeze-out: particle spectra are frozen in

Test of equilibration required to specify:

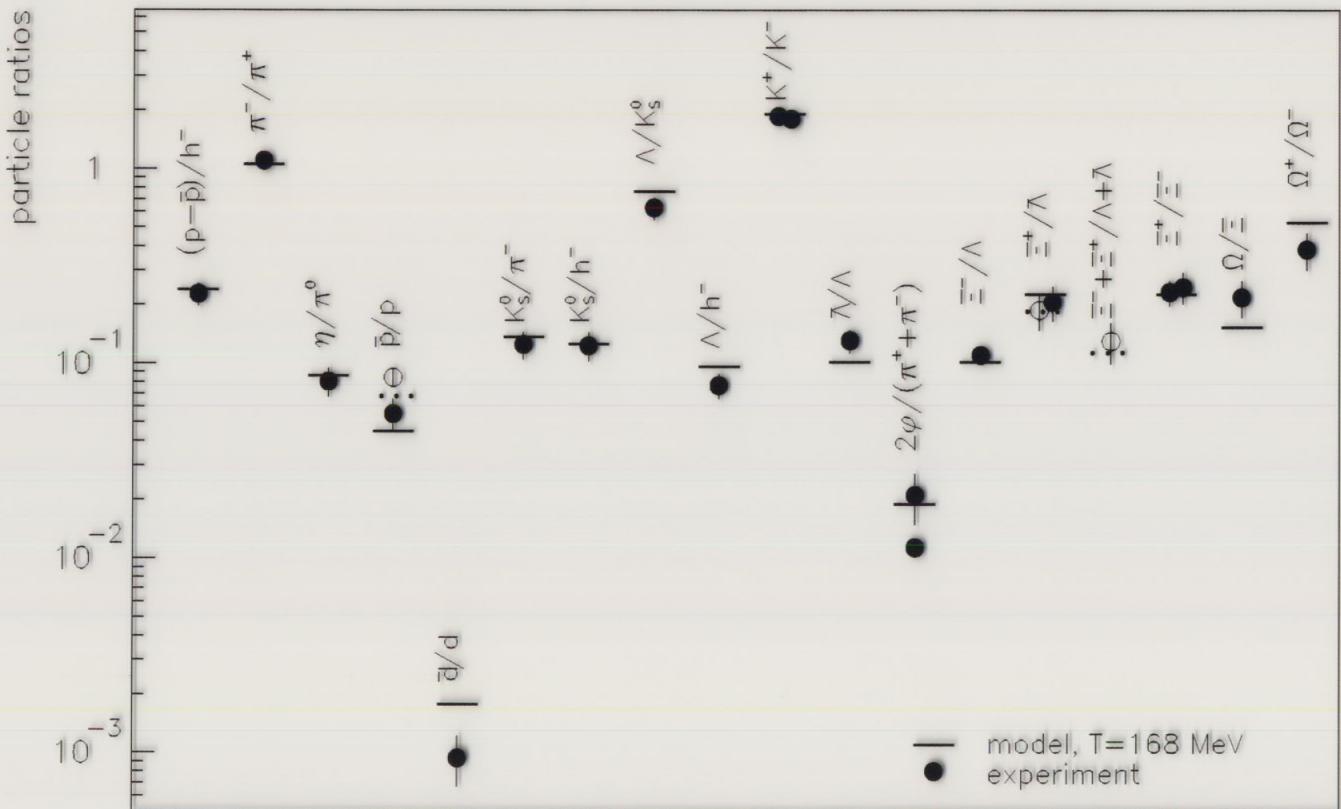
- i) level of observation: (multiplicities, spectra, correlations,..)
- ii) Statistical operator:

$$Z^{GC}(T, \vec{\mu}, V) = Tr[e^{-\beta(H - \mu_B B - \mu_S S - \mu_Q Q)}]$$

Test of chemical equilibrium for Pb-Pb at SPS

P. Braun-Munzinger, I. Heppe, J. Stachel

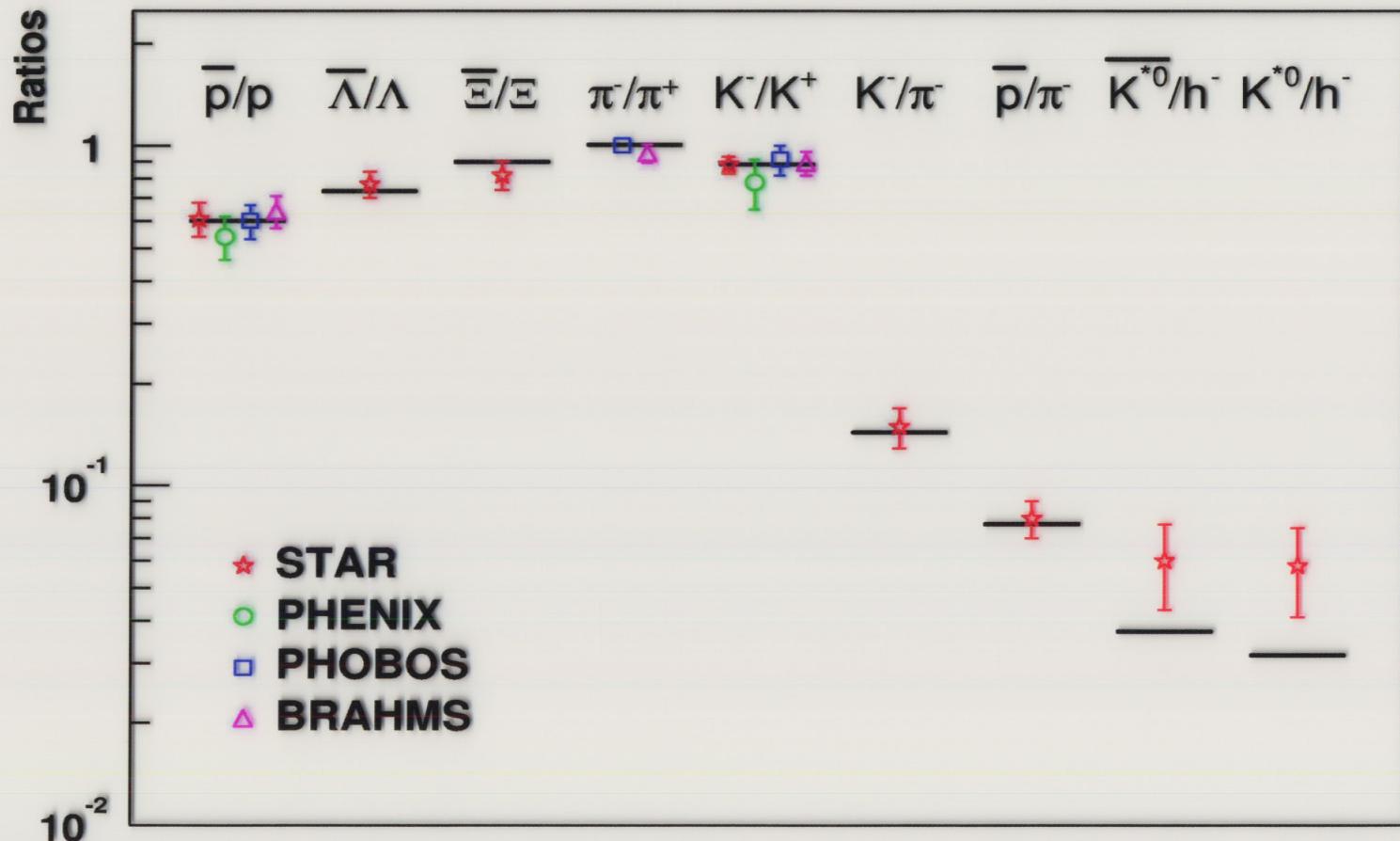
$$\varepsilon \approx 0.6 \text{GeV/fm}^3, \rho_B \approx 0.16/\text{fm}^3$$



Statistical description of RHIC data

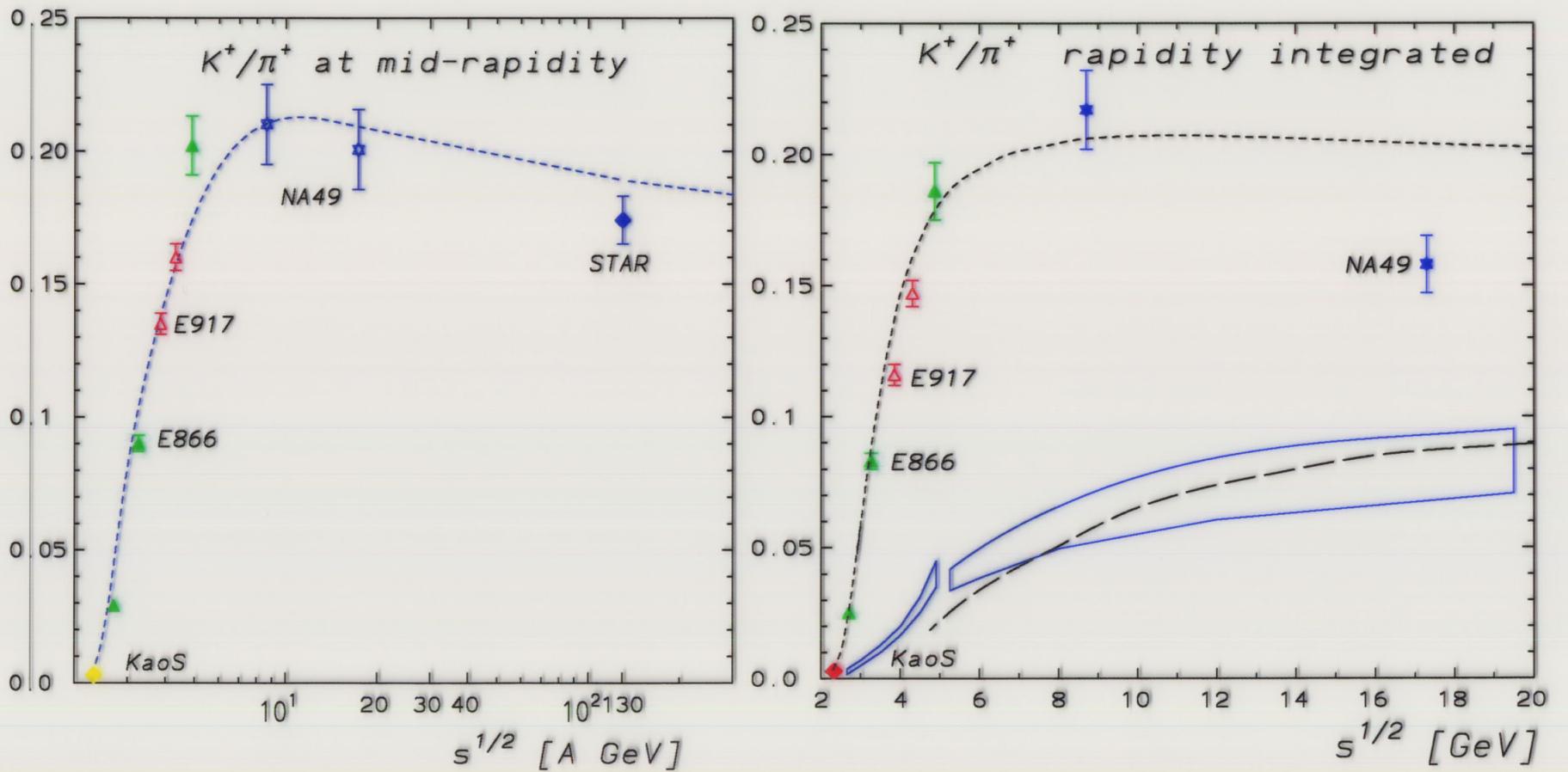
P. Braun-Munzinger, D. Magestro, J. Stachel, K.R.

$$T = 175 \pm 7 \text{ MeV} \quad \mu_B = 51 \pm 5 \text{ MeV}$$



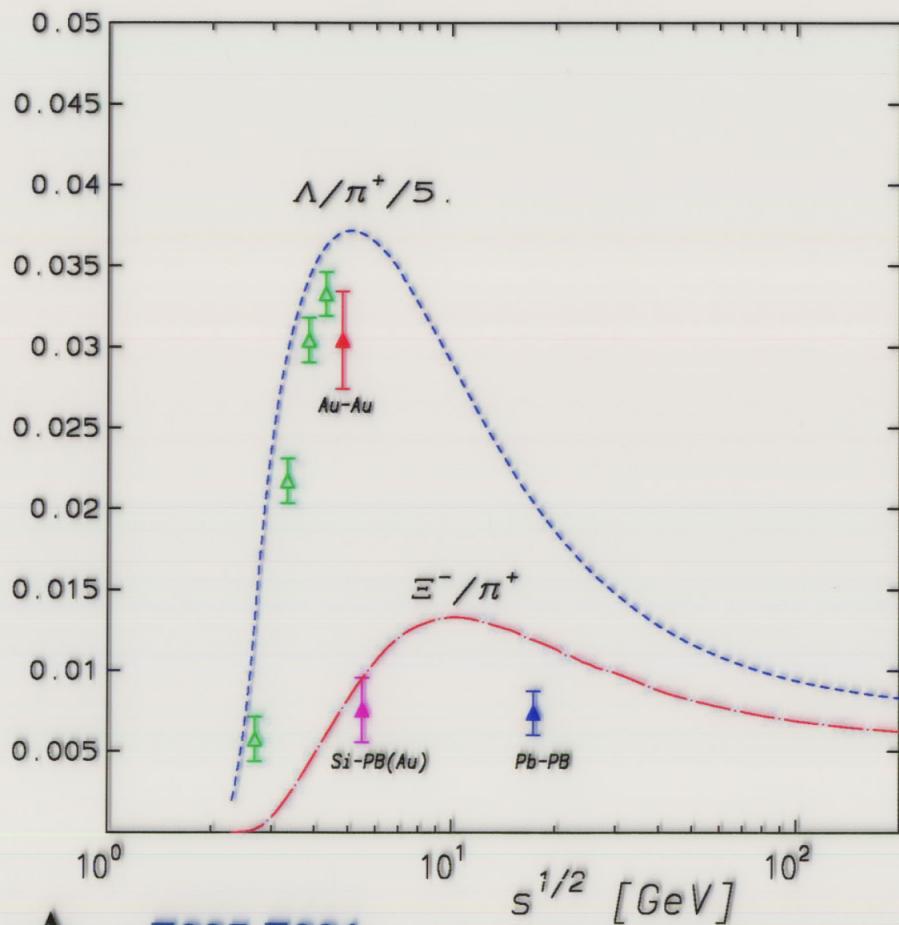
consistent with: Nu. Xu & Kaneta; Broniowski & Florkowski ; F. Becattini

Mid-rapidity and 4pi K^+/π^+ data from SIS to RHIC



Λ and Ξ^- energy dependence from SIS \rightarrow RHIC

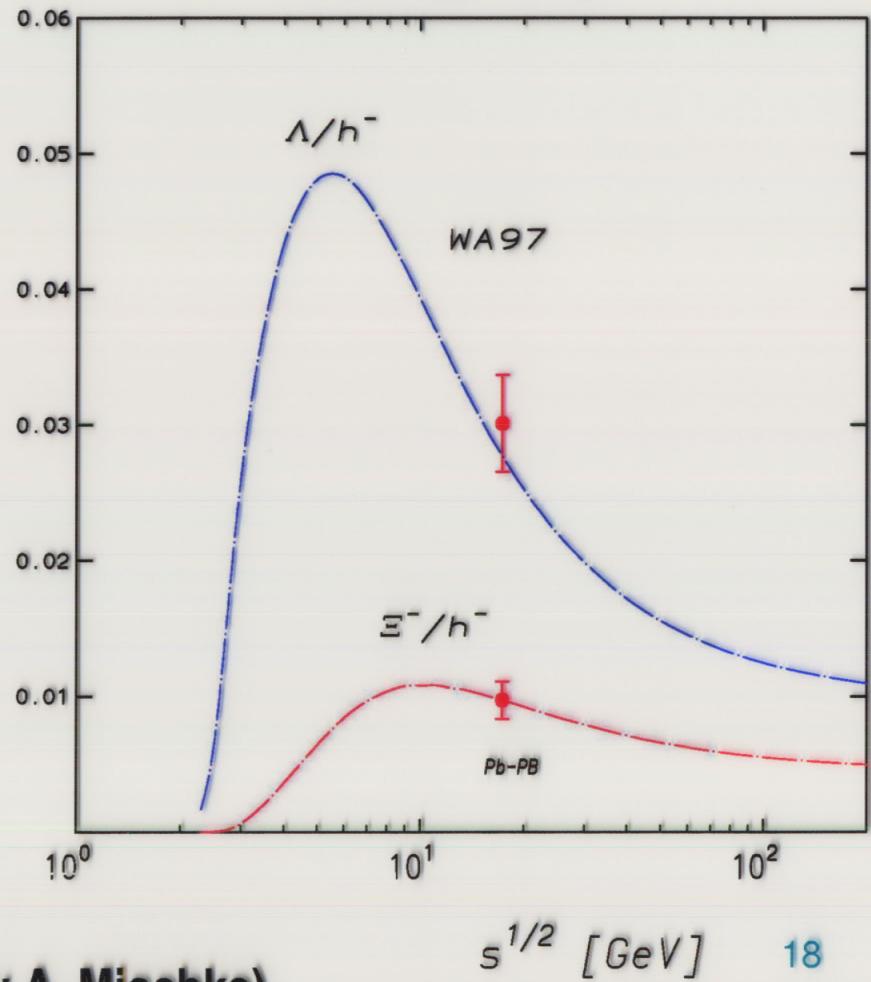
(4 π data)



Λ/π - E895, E891
- E866, 8917

(Λ/π ratio analysis by A. Mischke)

midrapidity



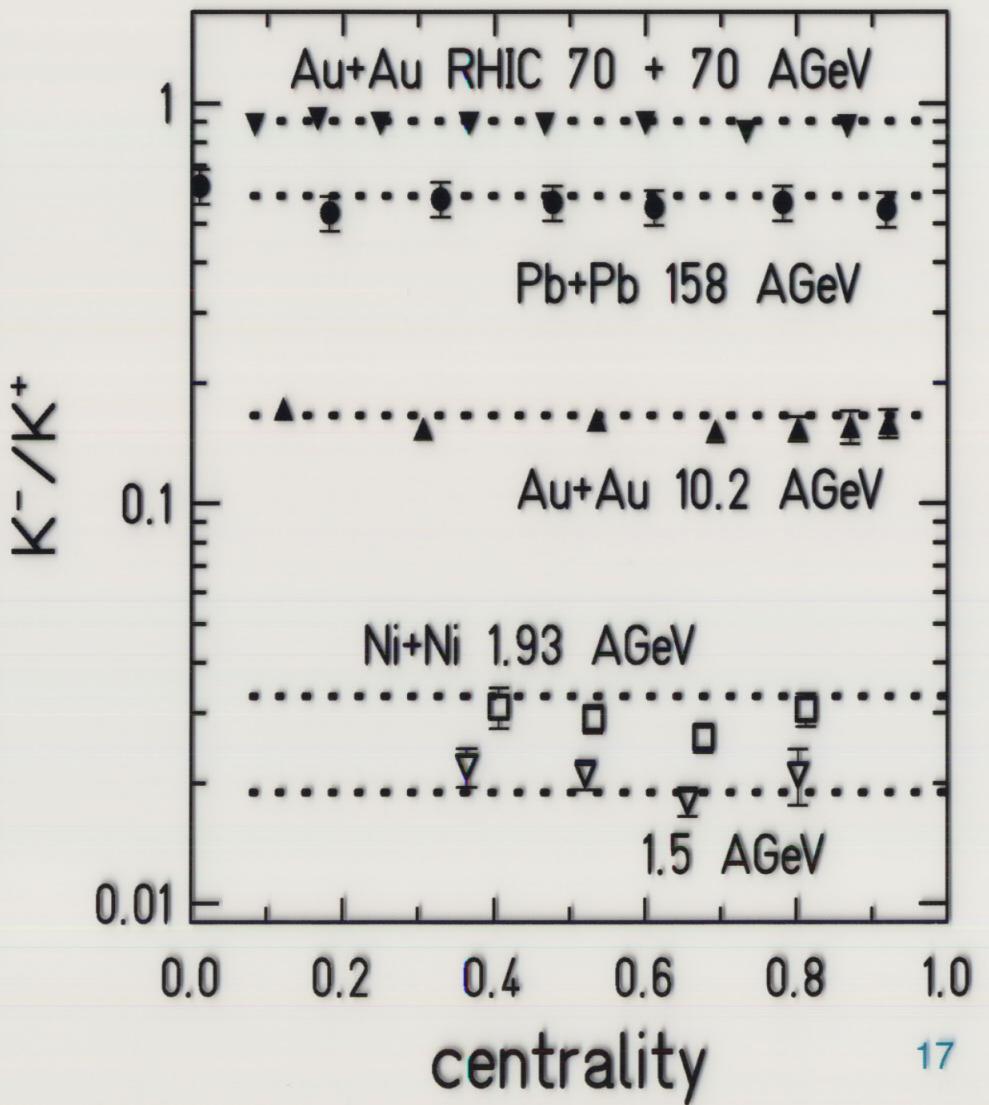
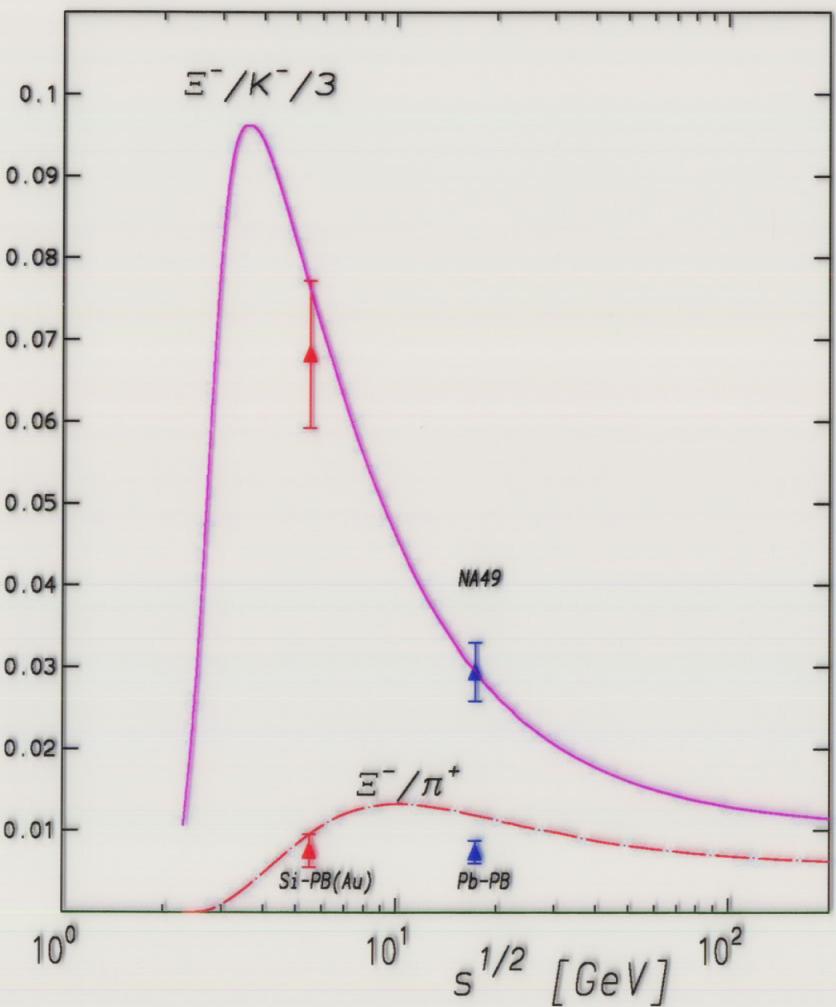
$s^{1/2}$ [GeV] 18

Particle production – energy dependence

E810,E802,NA49

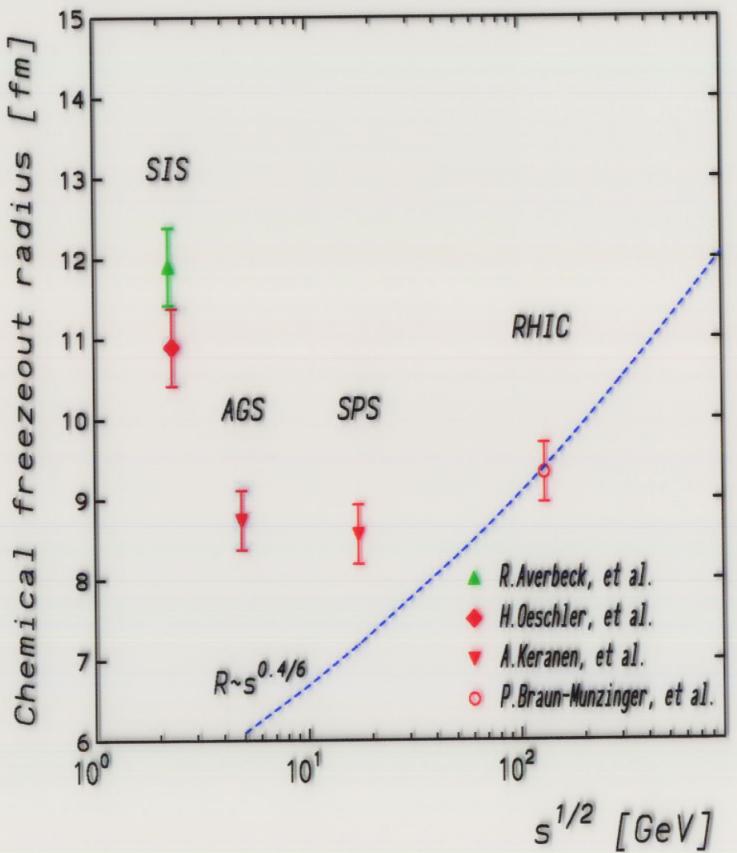
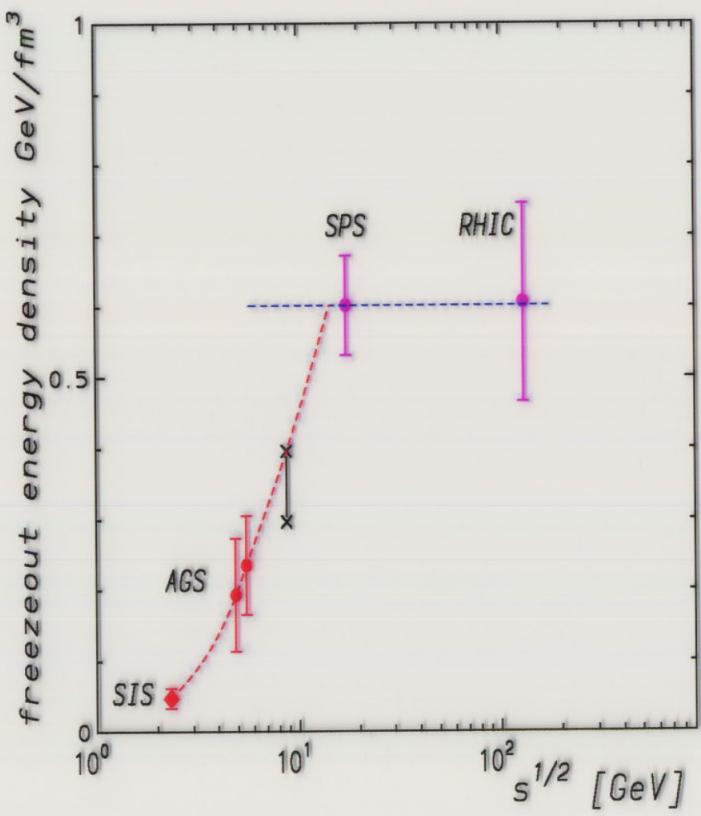
<=data from=>

STAR,NA49,E802,FOPI,KaOS

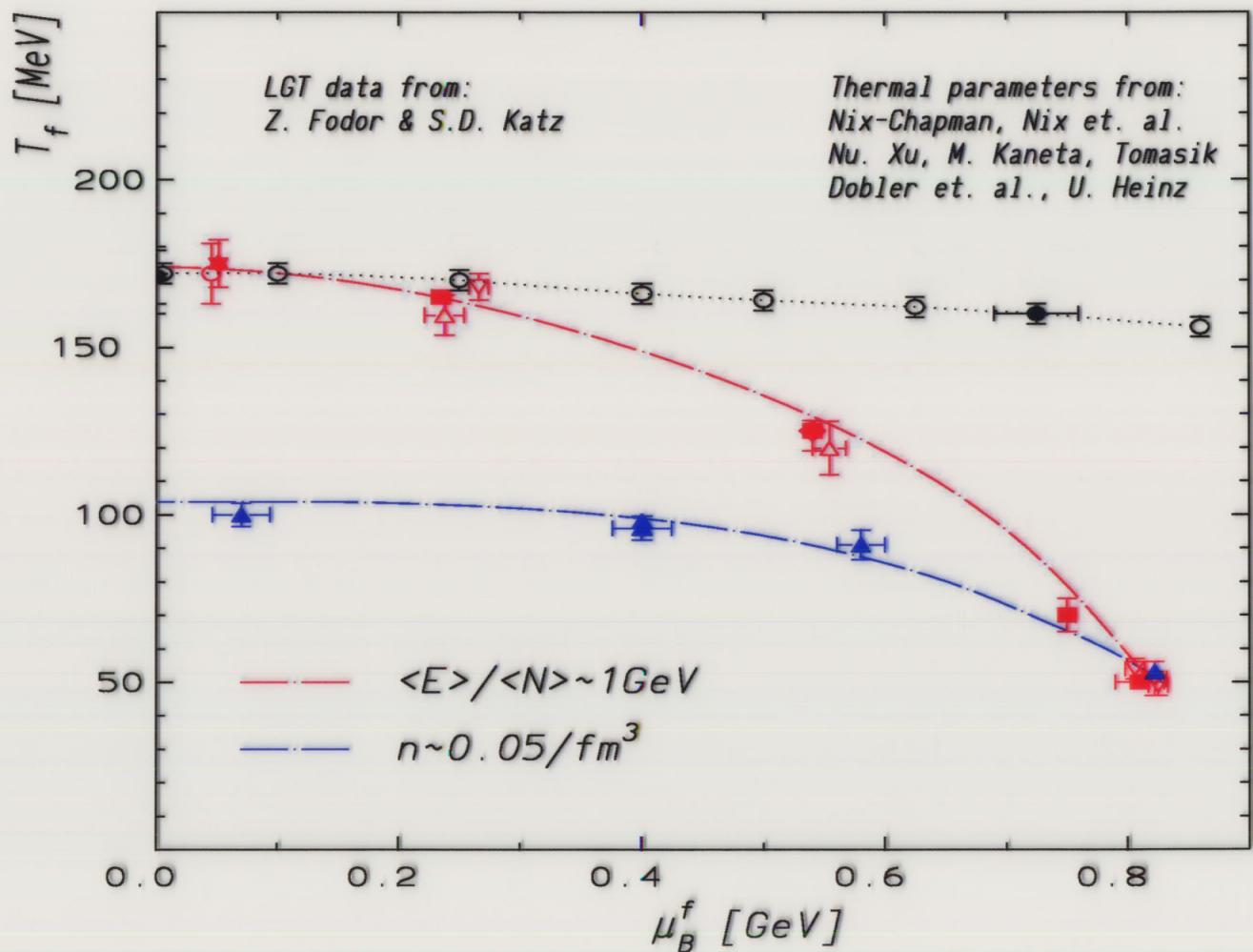


Thermal parameters at chemical freezeout

Energy Density Radius



Thermal, chemical and “critical” curves



First attempts to extract “critical parameters” from LGT at finite baryon density: based on the large volume behavior of the Lee-Yang zeros (Fodor & Katz)

Solution: convert to differential equation for the generating function

$$g(x, t) = \sum_{N=0}^{\infty} x^N P_N(t)$$

$$\frac{\partial g(x,t)}{\partial t} = \frac{L}{V_0}(1-x)\left(x\frac{\partial^2 g}{\partial x^2} + \frac{\partial g}{\partial x} - \boxed{\epsilon} g\right) \quad \boxed{\epsilon} \equiv \frac{G}{L} < N_\pi >^2$$

Equilibrium solution

$$g_{eq}(x) = \frac{I_0(2\sqrt{x\epsilon})}{I_0(2\sqrt{\epsilon})} \implies$$

$$P_N^{eq} = \frac{\epsilon^N}{I_0(2\sqrt{\epsilon})(N!)^2}$$

Kaon Multiplicity

$$< N_K >^{eq} = \left[\frac{\partial g(x)}{\partial x} \right]_{x=1} \implies$$

$$< N_K >^{eq} = \sqrt{\epsilon} \frac{I_1(2\sqrt{\epsilon})}{I_0(2\sqrt{\epsilon})}$$

Strangeness multiplicity equilibrium solution

$$\langle N_K \rangle^{eq} = \sqrt{\varepsilon} \frac{I_1(2\sqrt{\varepsilon})}{I_0(2\sqrt{\varepsilon})} \quad \text{with} \quad \sqrt{\varepsilon} \equiv \frac{Vd}{2\pi^2} m_K^2 T K_2\left(\frac{m_K}{T}\right)$$

↓

$$\langle N_K \rangle^{GC}$$

$$\langle N_K \rangle^{eq} = \langle N_K \rangle^{GC} \frac{I_1(2\langle N_K \rangle^{GC})}{I_0(2\langle N_K \rangle^{GC})}$$

(Multi) Strange Particle Multiplicities

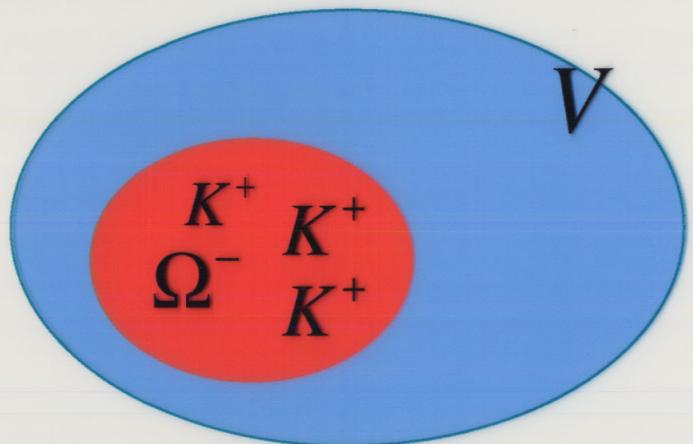
Hamieh, Tounsi, et al..

Consider : baryon free and charge neutral system
of volume V and temperature T

Impose : strangeness neutrality condition

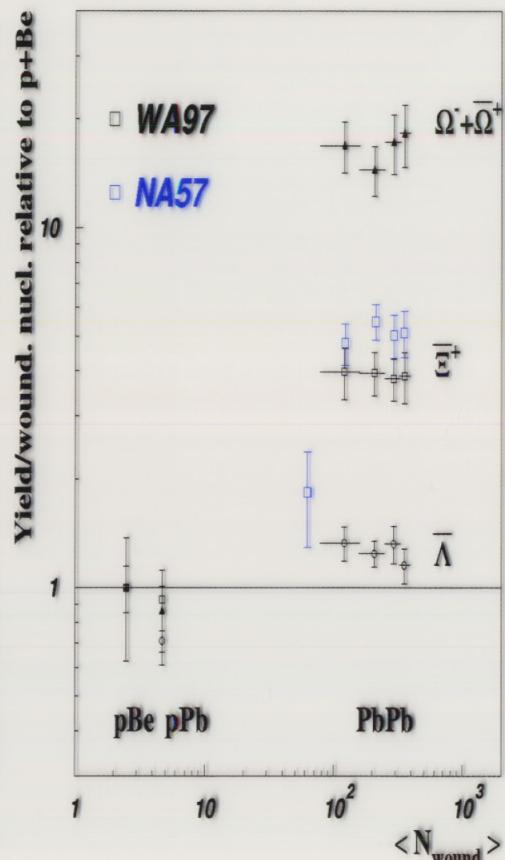
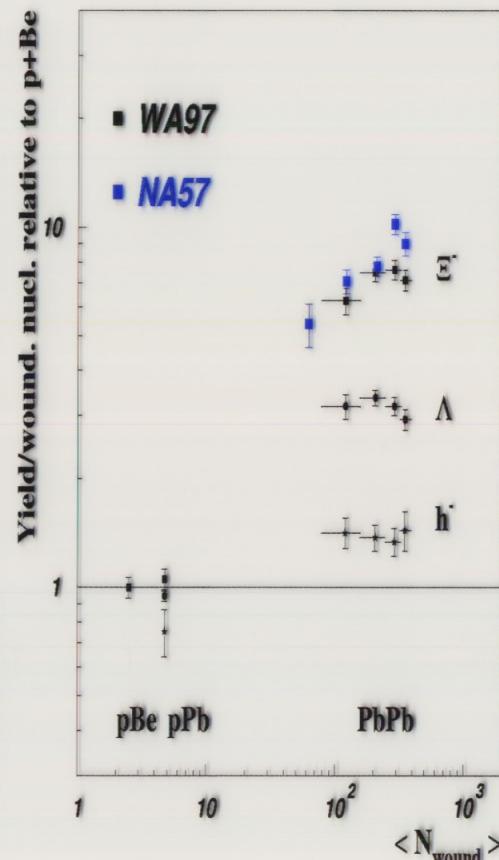
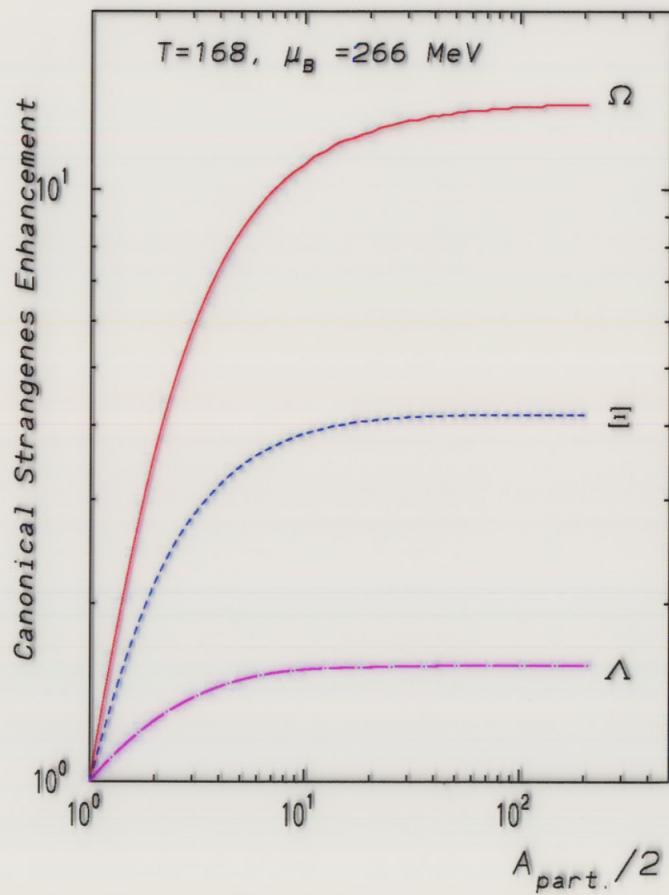
$$\frac{\langle N_s \rangle}{V} \approx w_s \frac{I_s(2Vw_{s=1})}{I_0(2Vw_{s=1})}$$

$$w_s \sim \int d^3 p e^{-\beta E_s}$$



$$\frac{\langle N_s \rangle^c}{V} \approx \begin{cases} Vw_{s=1} \gg 1: & w_s \\ Vw_{s=1} \ll 1: & w_s \left\{ [Vw_{s=1}]^{|S|} + .. \right\} \end{cases}$$

Statistical Model – Centrality Dependence approaching asymptotic grand-canonical limit

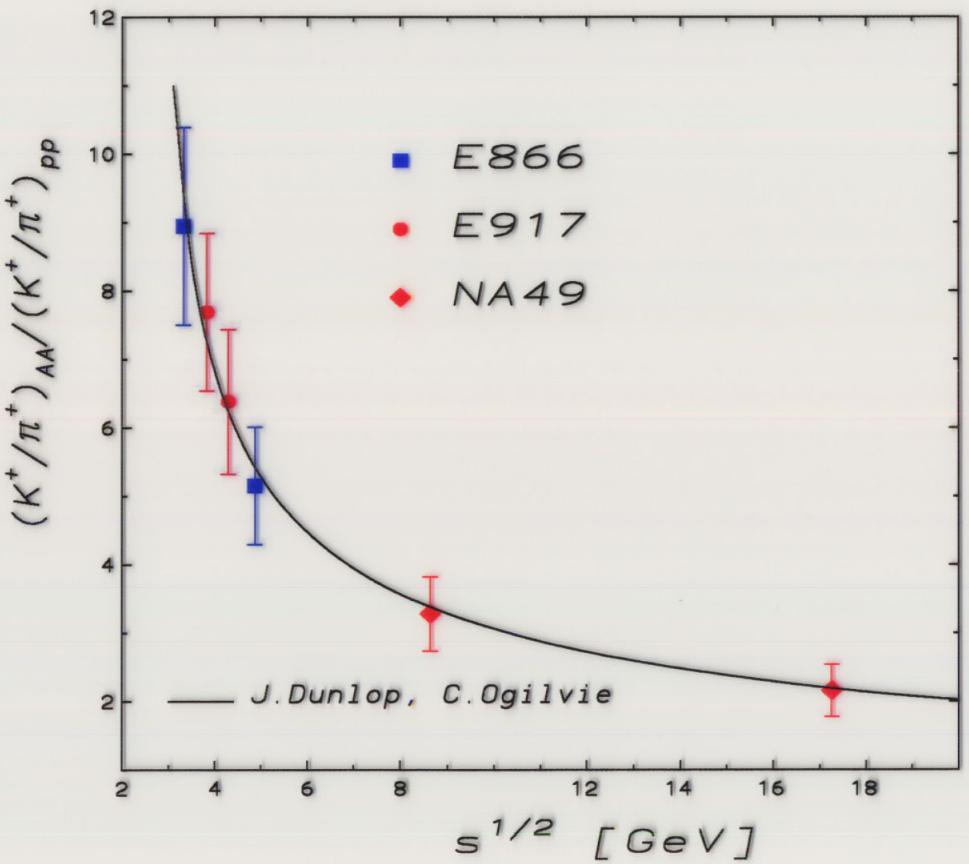
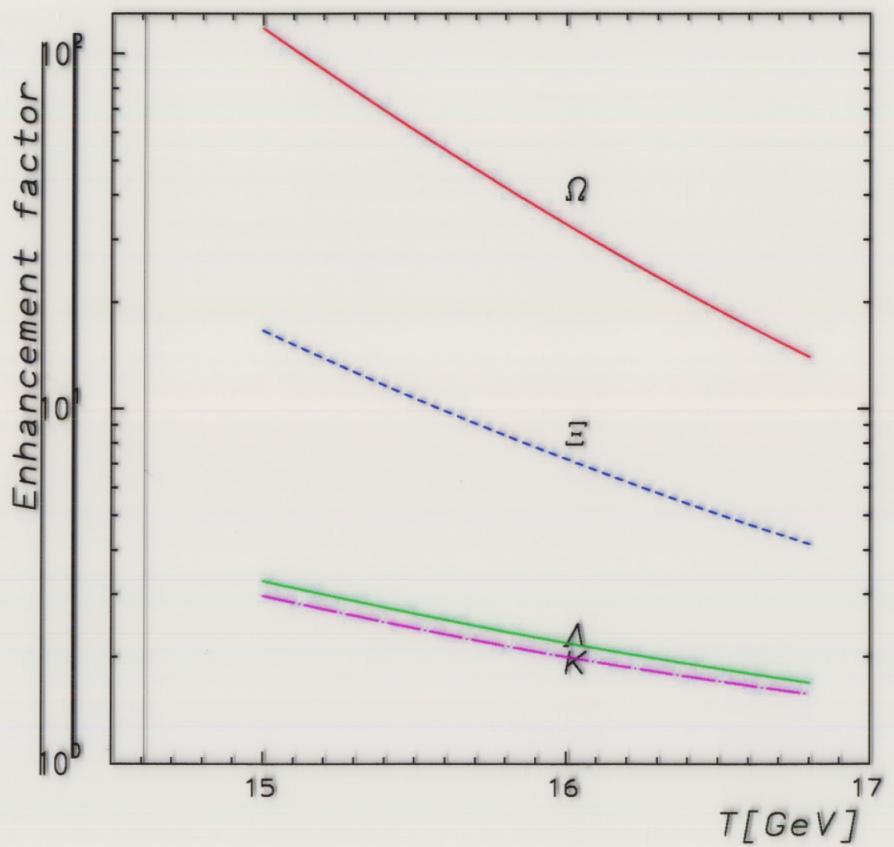


pattern as observed
by WA97

Strangeness enhancement

pp \Rightarrow AA

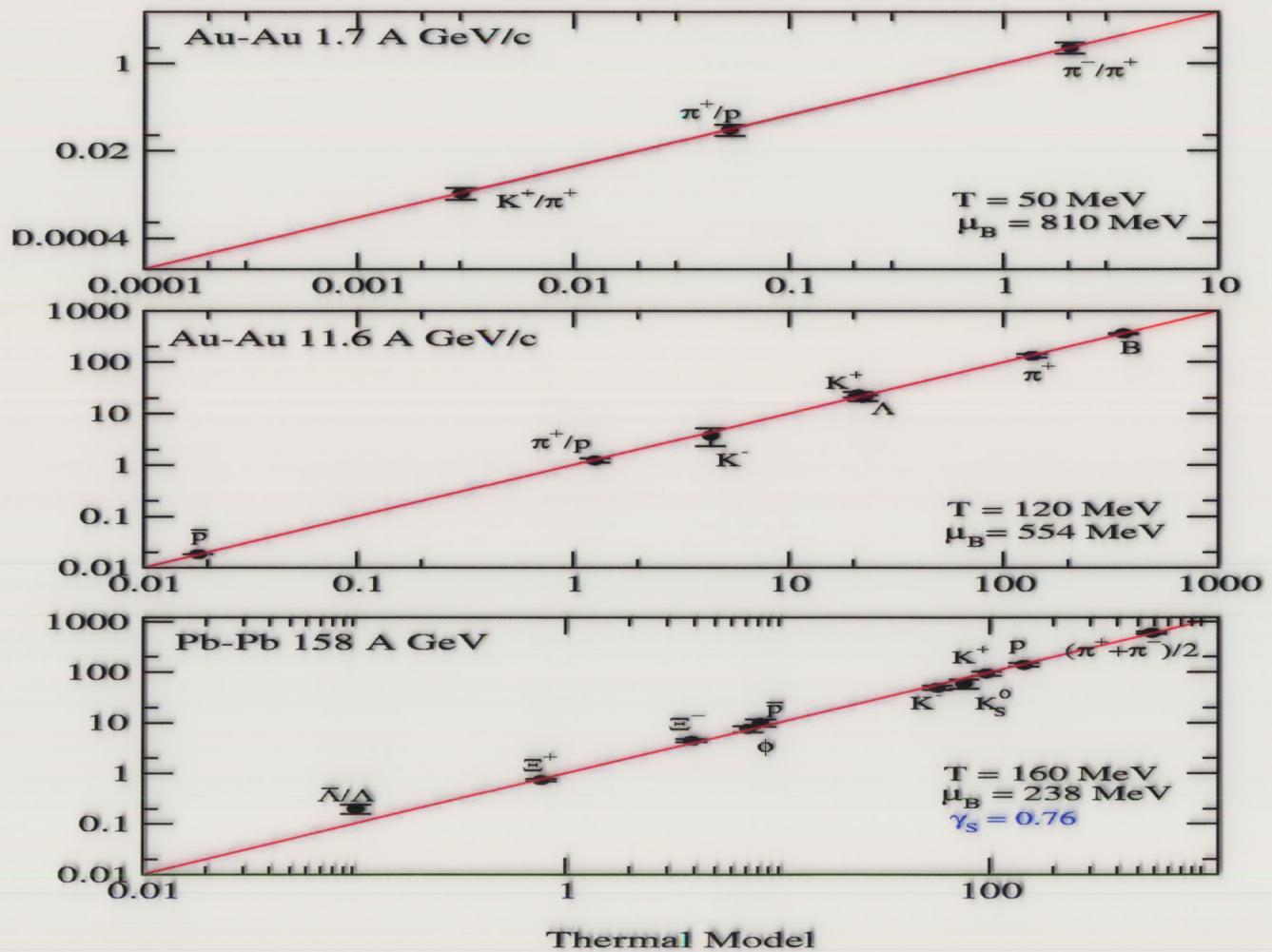
energy dependence



Strangeness enhancement
larger for lower energy

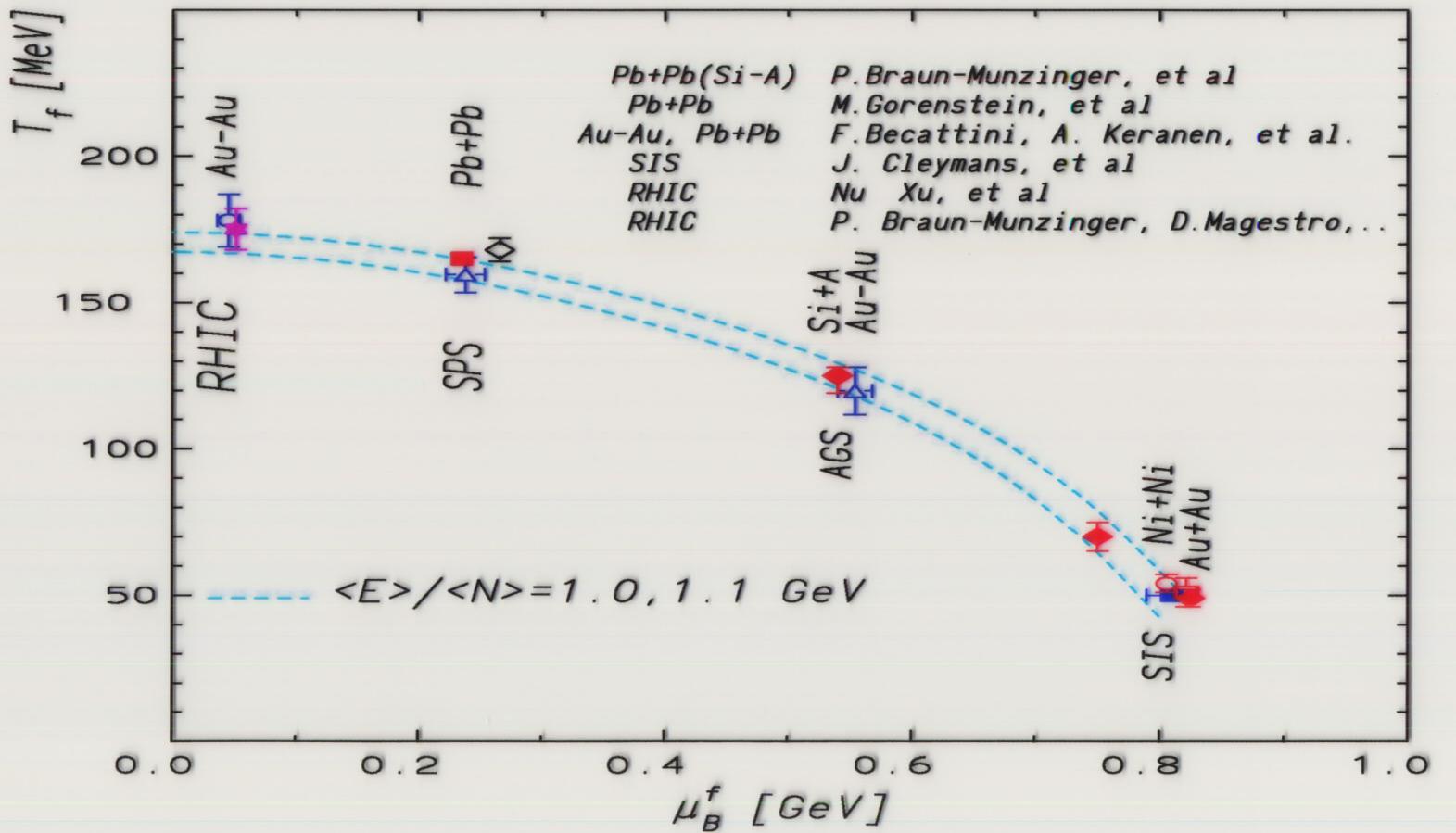
Chemical Equilibrium SIS - AGS – SPS

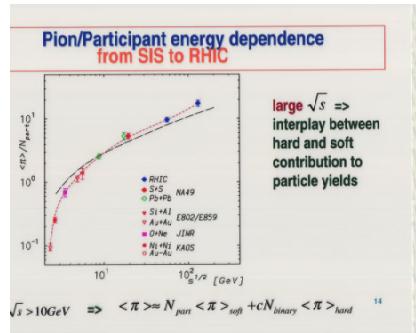
F. Becattini, J. Cleymans, A. Keranen, H. Oeschler, E. Suhonen, et al..



Unified freeze-out curve from SIS => RHIC

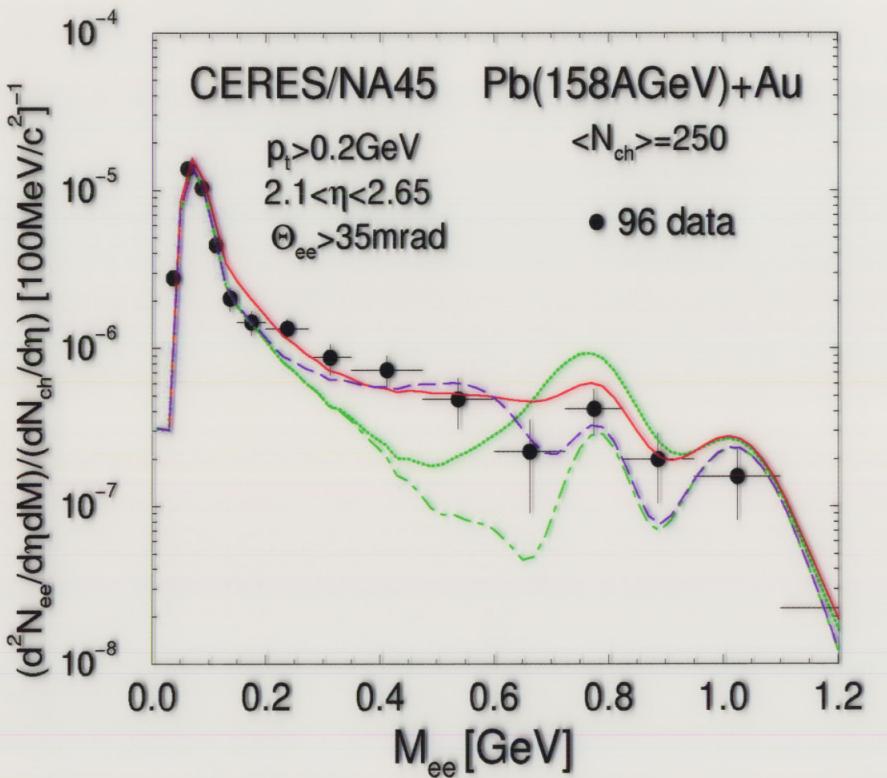
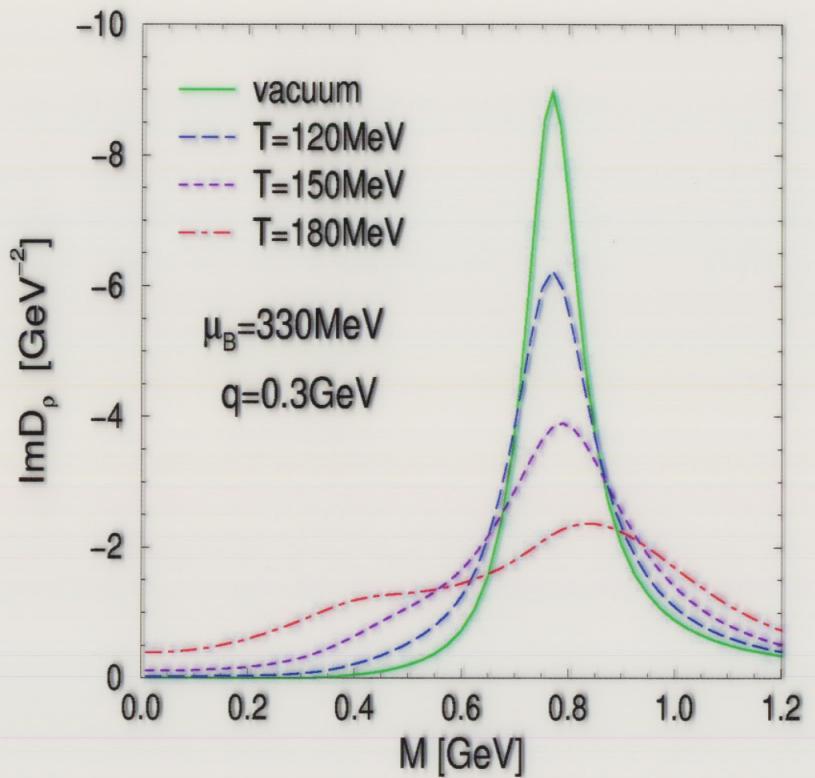
J. Cleymans, K.R





In medium effects –resonace broadening

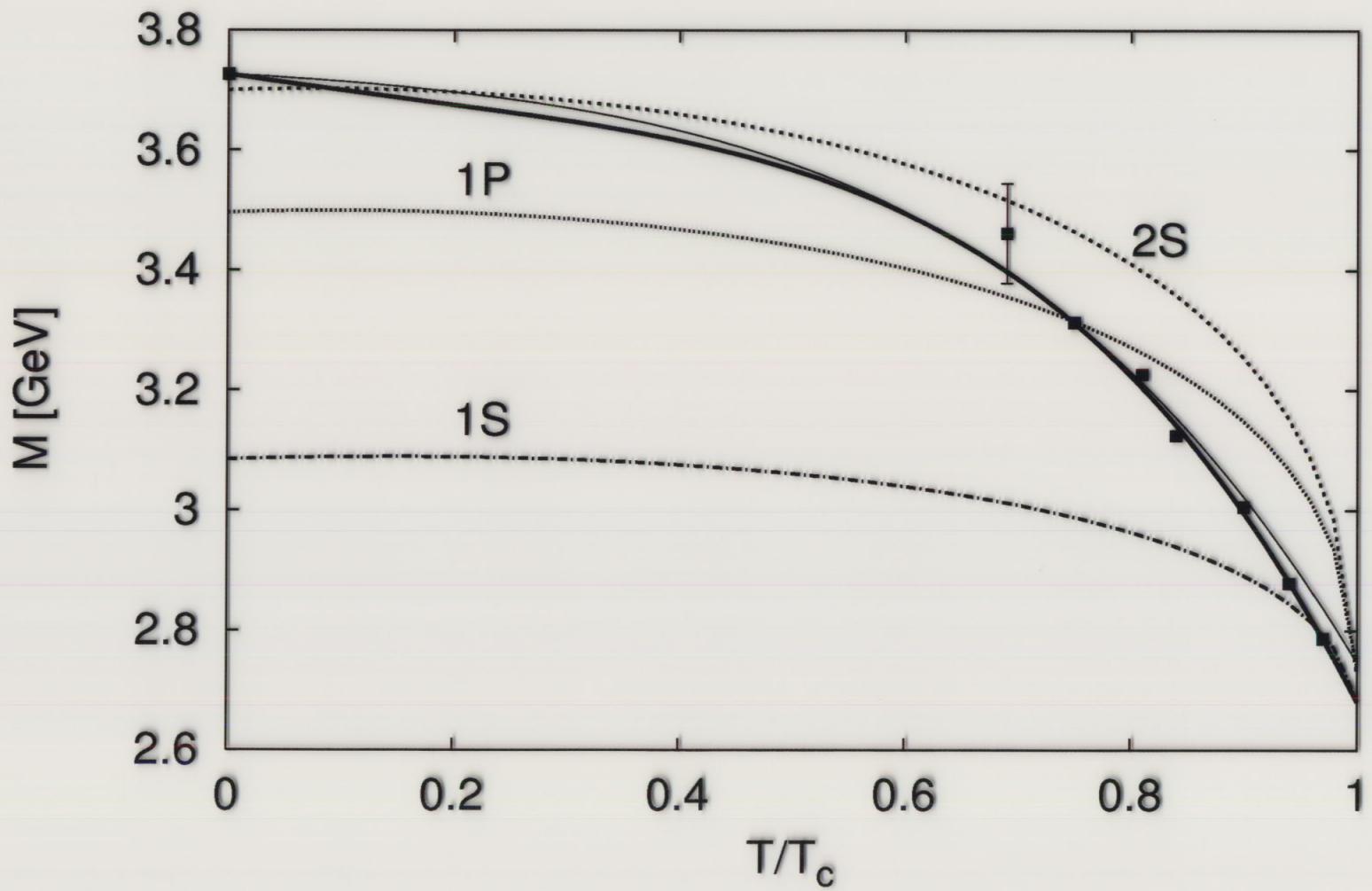
R. Rapp & J. Wambach



In medium effects => required to explain dilepton data , however are not included in statistical analysis of particle yields

Charm in-medium LGT results

S.Digal, P. Petreczky and H. Satz



Strangeness suppression – kinetic approach

C.M. Ko, V. Koch, Z. Lin, M. Stephanov, Xin-Nian Wang, K.R

Example:



Rate equation:

$$\frac{d \langle N_K \rangle}{dt} = \frac{G}{V} \langle N_\pi \rangle^2 - \frac{L}{V} \langle N_K \rangle^2$$

$$\begin{aligned} \langle N_K^2 \rangle &= \langle N_K \rangle^2 + \langle \delta N_K^2 \rangle \\ &\Downarrow \\ &\langle N_K \rangle \end{aligned}$$

Size of fluctuations



Equilibrium limit

$$\langle N_K \rangle \ggg 1$$

$$\langle N_K \rangle \ll 1$$

$$n_{K^+} \approx m_{K^+}^2 T K_2 \left(\frac{m_{K^+}}{T} \right) \times$$

$$n_{K^+} \approx m_{K^+}^2 T K_2 \left(\frac{m_{K^+}}{T} \right)$$

$$V m_{K^-}^2 T K_2 \left(\frac{m_{K^-}}{T} \right)$$

Strangeness kinetic – general approach

$P_N(t)$ probability of finding N pairs of K^+K^-



Transition probability from $N \rightarrow N+1$:

$$\frac{G}{V} < N_\pi >^2$$

Transition probability from $N \rightarrow N-1$:

$$\frac{L}{V} N^{-2}$$

$$\frac{dP_N}{dt} = \frac{G}{V} < N_\pi >^2 P_{N-1} + \frac{L}{V} (N+1)^2 P_{N+1} -$$

$$\frac{G}{V} < N_\pi >^2 P_N - \frac{L}{V} N P_N -$$

$$< N_K > = \sum_N N P_N$$